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The Effects of EGR on the Performance and Exhaust Emissions of a Diesel Engine Operated on Diesel Oil and Pongamia Pinata Methyl Ester (PPME)

S. Ghosh[1], D. Dutta[2],
[1,2]Asst Prof., Camellia School of Engineering & Technology, Barasat, Kolkata - 700124, W.B., India

Abstract:–An experimental study was carried out to investigate and demonstrate the influence of using Exhaust Gas Recirculation (EGR) of different rates on the engine performance parameters such as specific fuel consumption, brake thermal efficiency and emission characteristics such as hydrocarbon emission, smoke density and NOx emission of a single cylinder; water cooled, four-stroke, diesel engine with eddy current dynamometer. The engine was fuelled with commercial grade diesel of heating value 42500kJ/kg and Pongamia pinata methyl ester (PPME) of heating value 37255kJ/kg. The experimental setup for the experiments was developed. Exhaust gas recirculation system was tested with three EGR percentages. i.e. 0 %, 5 %, 10 % and compared the performance and emission characteristics of the engine with the fuels. The speed of the engine was kept constant (1500 rpm) and it is observed that Exhaust Gas Recirculation (EGR) has considerable reduction in oxides of nitrogen (NOx).

Keywords:–Diesel engine, NOx, EGR, Pongamia piñata methyl ester, Brake thermal efficiency, Specific fuel consumption.

I. INTRODUCTION

Despite diesel engines have advantages they produce higher levels of NOx and smoke emissions which have significant effect on human, animal, plant, and environmental health and welfare. The search for energy independence and concern for a cleaner environment have created significant interest in biodiesel, despite its shortcomings. The use of biodiesel in diesel engines has both economic and environmental benefits. Biodiesel is an alternative diesel fuel which can be obtained from the transesterification of vegetable oils or animal fats. The use of biodiesel in diesel engines does not require any engine modification. An important property of biodiesel is its oxygen content which is usually not contained in diesel fuel. Biodiesel gives considerably lower emissions of PM, carbon monoxide (CO) and hydrocarbon (HC) without any extra fuel consumption or engine performance penalties. Exhaust gas recirculation (EGR) can be used with biodiesel in the diesel engines. EGR is an effective technique of reducing NOx emissions from the diesel engine exhaust.

Ohigashi et al (1971) reported that exhaust gases contains mixture of CO, nitrogen, water vapors etc. Exhaust gases displaces the fresh oxygen for the combustion. The mixture has higher specific heat compared to the supplied fresh air, this increases the total heat capacity of the working gases in the engine cylinder and thus lowers the peak gas temperature and reduces rate of NOx formation. [1]. A.K. Agrawal et al. (2004) suggested that in diesel engines NOx formation is very much depends upon temperature. To reduce NOx emission in the exhaust, it is necessary to keep combustion temperature under control. [2]. Yokomura et al. (1994) have explained that exhaust gas recirculation is one of the most effective ways for nitrogen oxides (NOx) reduction process. [3]. Ladommatos et al. (1998) tested the effect of exhaust gas recirculation on diesel engine emissions. They noticed a large reduction in NOx emissions at the expense of higher particulate and un-burnt hydrocarbon emissions. [4]. D.Agarwal (2006) suggested that controlling the NOx emissions primarily requires reduction of in-cylinder temperatures. [5].Y. Yoshimoto (1999) reported that the application of EGR results in higher fuel consumption and emission penalties, also EGR increases HC, CO, and PM emissions along with slightly higher specific fuel consumption. [6].

Zheng, G. T. Reader (2004) et al. have studied the effect of EGR on NOx emission and reported that the EGR rates are sufficient for high load, also as the load increases; diesel engines tend to generate more smoke because of reduced oxygen. Therefore, EGR, although effective to reduce NOx, further increases the smoke and PM emissions. [7]. Abu-Jrai et al, (2007) have analyzed the effect of exhaust gas recirculation (EGR) on pollutant emission in diesel engine. [8]. Santoh et al. (1997) carried out experiment on a naturally aspirated single cylinder DI diesel engine with various combinations of EGR, fuel injection pressures, injection timing and intake gas temperatures affect exhaust emissions and they found that NOx reduction ratio has a strong correlation with oxygen concentration regardless of injection pressure or timing. EGR lowers the average combustion temperature and reduces the oxygen intake gases that adversely affect the smoke emission and soot formation. They also suggested that for a given level of oxygen concentration the cooled EGR reduces more NOx with less EGR rates than does at hot EGR. [9]. Saravanan et al. (2008) performed a series of test on a single cylinder water cooled DI diesel engine with hydrogen was used as dual fuel mode with EGR technique. They reported increase in brake thermal efficiency and lowered smoke level, particulate and NOx emissions due to absence of carbon in hydrogen fuel. [10]. Hountalas et al. (2008) have presented 3D-multi dimensional model to examine the effect of EGR temperature on a turbocharged DI diesel engine with three different engine speeds. They reported that high EGR temperature affects the engine brake thermal efficiency, peak combustion pressure, air fuel ratio and also soot emissions, and the combined effect of increased temperature and decreased O_2 concentration resulted low NOx emissions. Also they suggested that EGR cooling is necessary to retain the low NOx emissions and prevent rising of soot emissions without affecting the engine efficiency at high EGR rates. [11].

Abd-Alla et al. (2001) have done experiments on a dual fuel (gaseous fuel- methane with diesel as pilot fuel) mode direct injection diesel engine to study the effect of inlet air temperature by the way of mixing of hot EGR and addition of diluents gas such as CO_2 and N_2 .They observed that the addition of CO_2 gas in the intake charge increased un-burnt hydrocarbon emission (UBHC) but moderate reduction of NOx emission. By increasing the intake charge temperature NOx emission was increase with decrease in UBHC. The brake thermal efficiency and power output increased due to reduced ignition delay. Also they suggested that the performance was improved at low load condition when the intake air temperature was increased. [12].

The main objective of the present work is to investigate the effect of exhaust gas re-circulation on the engine performance and exhaust emission and compared using Pongamia piñata methyl ester (PPME) and diesel fuel.

II. EXHAUST GAS RE-CIRCULATION SYSTEM

In exhaust gas recirculation process, the engine out exhaust gas is re-circulated to the engine. Oxides of nitrogen are formed when the temperature inside the combustion chamber exceeds the critical temperature so that the molecules of nitrogen and oxygen combine [6]. Inter-mixing the incoming air with re-circulated exhaust gas basically cuts off some percentage of the oxygen going into the combustion chamber and lowers the adiabatic flame temperature. The exhaust gas increases the specific heat of the mixture and lowers the peak combustion temperature. NOx formation progresses faster at higher temperatures. EGR serves to limit the formation of NOx. There is no doubt that EGR is very effective in reducing oxides of nitrogen, but it also has adverse effects on the engine efficiency. As it contains a lot of particulate matter, it may also contaminate the lubricating oil and can also foul the intake manifold [6].

III. EXPERIMENTAL SETUP

An experimental investigation was carried out to investigate the influence of exhaust gas recirculation on performance a diesel engine. The engine used for the investigation was computerized single-cylinder, four-stroke, and water cooled diesel engine with eddy current dynamometer. The technical specifications of the engine are given in Table I, and the schematic of the experimental setup is shown in Figure 1. The power output of the engine was measured by an electrical dynamometer. AVL gas analyzer was used for the measurement of amounts of exhaust emissions. For smoke opacity measurement AVL smoke meter was used. Rota meters were used to measure the volume flow rates of inlet charge as well as exhaust gas to be re-circulated. Digital control panel was used to collect data such as torque, water flow of engine etc. A known quantity of exhaust gas with air was re-circulated into the combustion chamber and was performed with manually controlled EGR valve. The exhaust gas that came out from the engine was at very high pressure and temperature. The measurements were taken after steady state of the engine for each set of readings.

Table1. Engine specifications

Type of engine	Water cooled Four stroke
Number of cylinder	one
Bore	87.4mm
Stroke	110mm
Compression ratio	17.5:1
Rated speed	1500 rpm
Maximum Power	5.2kW(7hp)
Maximum torque	30N-m

Table-2: Properties of Test fuels

Properties	Diesel	PPME
Fuel Density (kg/m3)	835.8	967
Low heating value (kJ/kg)	42500	37255
Flash Point °C	56	206
Viscosity (cSt) at38°C	3.85	29.8

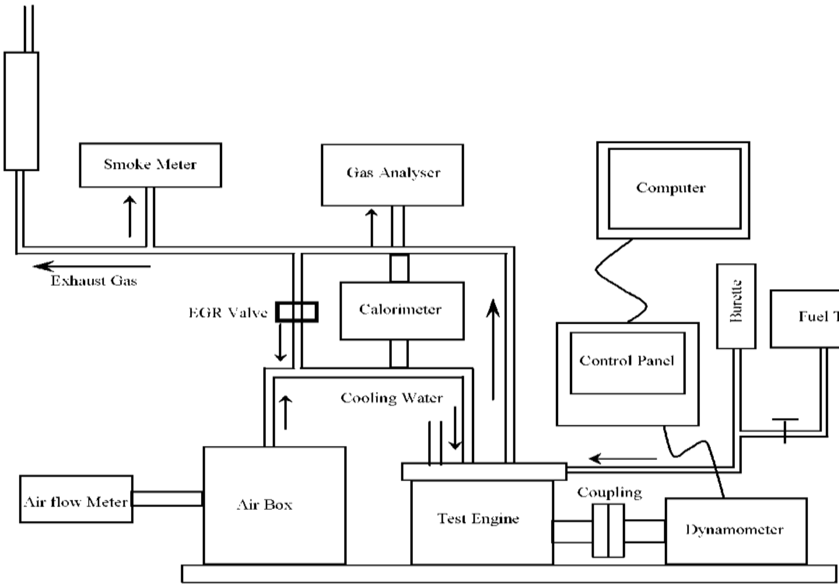

Figure 1. Schematic of Experimental Setup

IV. CALCULATION OF THE EGR RATE

When the impact of EGR on the emissions is assessed, it is essential to know the EGR ratio

$$\%EGR = \frac{\text{Mass of EGR}}{\text{Mass of total intake mixture into the cylinder}} \times 100$$

Another way to define the EGR ratio is by the use of CO_2 concentration (Baert et al 1999). [13].

$$\text{EGR ratio} = \frac{[CO_2]\ \text{intake} - [CO_2]\ \text{ambient}}{[CO_2]\ \text{exhaust} - [CO_2]\ \text{ambient}}$$

V. RESULTS AND DISCUSSIONS

The experiment was carried out in a four stroke single cylinder, water cooled diesel engine using diesel and Pongamia pinata oil methyl ester (PPME) at 1500 rpm and different EGR rates to study the effect of EGR on the performance of the engine like brake thermal efficiency and specific fuel consumption and emission characteristics like HC emission smoke density and NOx concentration in the tail pipe emissions. Higher amount of smoke emission is observed in the exhaust when the engine is operated with EGR compared to without EGR in both cases. Smoke emissions increases with increasing engine load and EGR rates.EGR reduces availability of oxygen for combustion of fuel, which results in relatively incomplete combustion and increased formation of PM and reducing NOx emissions from diesel engine. Using biodiesel in diesel engine, smoke is decreased with increase in NOx. Thus, biodiesel with EGR can be used to reduce NOx and smoke intensity simultaneously.

1. Brake thermal efficiency

Fig. 2. shows the variations of brake thermal efficiency with brake power of diesel and Pongamia pinata oil methyl ester (PPME) respectively with and without EGR at constant speed 1500 rpm of the engine. It is observed from the figures that the brake thermal efficiencies are increased with increase in load with or without EGR at lower load. This is due to re-burning of hydrocarbons that enter in to the combustion chamber during suction with the re-circulated exhaust gases. Brake thermal efficiency of diesel fuel is higher than PPME at all loading conditions with and without EGR operations due to higher heating value of the diesel fuel. At full load operation the brake thermal efficiency marginally decreases in both cases with the increase of the EGR

rate. At full load condition brake thermal efficiency of diesel fuel is 3.2% and 4% respectively higher than PPME when operated on without and with10% EGR due to low calorific value and high viscosity of PPME.

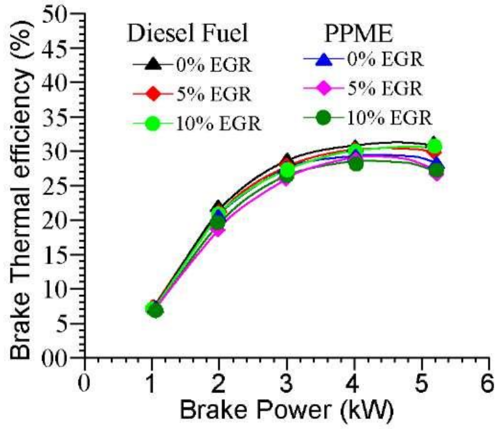

Figure 2. Variation of brake thermal efficiency with brake power for diesel and PPME

2. Specific Fuel Consumption

Fig. 3 shows the variations of SFC with brake power for diesel and Pongamia pinata methyl ester (PPME) respectively with and without EGR at constant speed 1500 rpm of the engine. The specific fuel consumptions are lower for diesel at all loads operated with EGR and without EGR when compared to PPME. So, to get constant power output more bio-fuel mixtures are required. However, at higher loads of the engine, SFC with EGR is almost similar to that of without EGR for diesel fuel but slightly higher with PPME. The specific fuel consumption is about 6 % higher with Pongamia pinata methyl ester (PPME) at full load operation with 10% EGR.

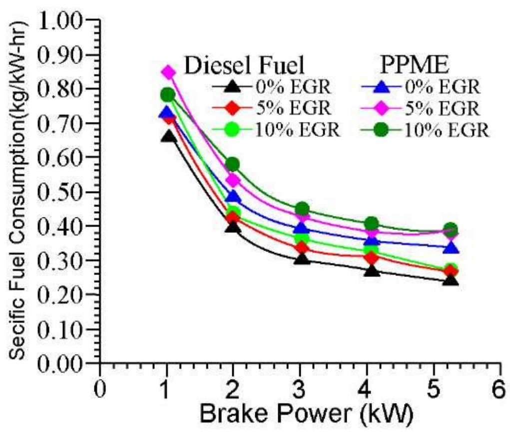

Figure 3. Variation of Specific Fuel Consumption with Brake Power

3. Oxides of nitrogen emission (NOx)

Fig. 4 shows the variations of NOx emissions with brake power of diesel and Pongamia pinata methyl ester (PPME) respectively with and without EGR at constant speed 1500 rpm of the engine. It is observed from the figure that the bio-diesel (PPME) emits higher NOx than diesel fuel at all loading conditions due to higher oxygen content of bio-diesel provide high local temperature and complete combustion of the bio-diesel. The emission of NOx tends to decrease significantly with the increase of EGR rate for all loading conditions for both the fuels due to reduction of oxygen concentration for the presence of inert gases such as CO_2 and H_2O in the cylinder that decreased the flame temperatures in the combustion chamber. At full load condition NOx emission for diesel and PPME are respectively 810ppm and 958ppm at constant speed of the engine without EGR. From the figure it is observed that maximum NOx reduction occurs with 10% EGR. At full load condition reduction of NOx for PPME and diesel was respectively 150ppm and 130ppm with 10% EGR.

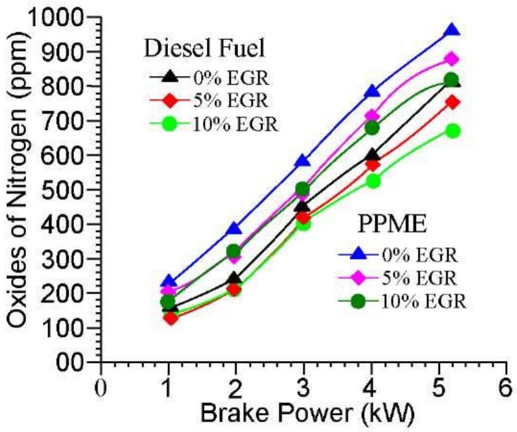

Figure 4. Variation of Oxides of Nitrogen with Brake Power

4. Smoke density (HSU)

Fig. 5 shows the variations of smoke emissions with brake power of diesel and Pongamia pinata methyl ester (PPME) respectively with and without EGR at constant speed 1500 rpm of the engine. Higher amount of smoke emission is observed in the exhaust when the engine is operated with EGR compared to without EGR in both cases. Smoke emissions increases with increasing engine load and EGR rates.EGR reduces availability of oxygen for combustion of fuel, which results in relatively incomplete combustion and increased formation of PM and reducing NOx emissions from diesel engine. Pongamia pinata methyl ester (PPME) showed 6% lower smoke compared to diesel oil at full load condition when operated without EGR due to the oxygen content of the bio-fuel molecules resulting more complete combustion of the bio-diesel. At full load condition 2.5% less smoke emission is observed for PKME with 10% EGR.

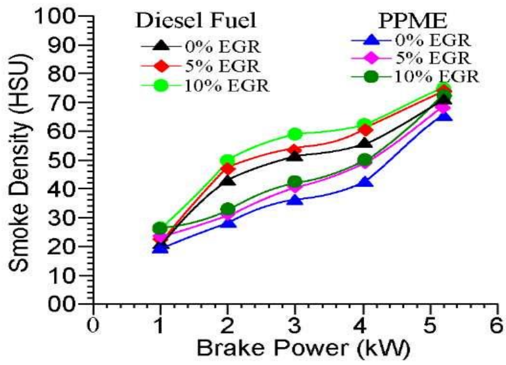

Figure 5. Variation of Smoke Density with Brake Power

5. Hydrocarbon emission (HC)

Figure 6 shows the variations of hydrocarbon (HC) emissions with brake power of diesel and Pongamia pinata methyl ester (PPME) respectively with and without EGR at constant speed 1500 rpm of the engine. From the figure it is observed that hydrocarbon emission increases with the increase with load in the engine due to insufficient amount of oxygen in the combustion chamber resulting incomplete combustion. Due to presence of molecules of oxygen in Pongamia pinata methyl ester emits lower HC than diesel fuel. At full load condition PPME emits 7.5% and12% lower HC when operated without EGR and with10% EGR.

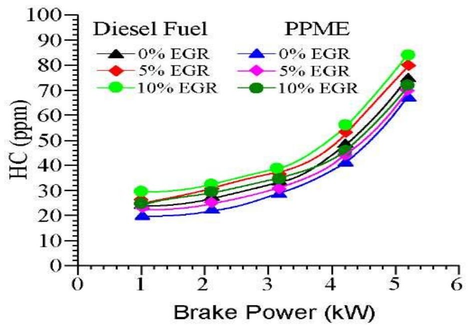

Figure 6. Variation of Hydrocarbon Emission with Brake Power

VI. CONCLUSION

An experimental investigation was done on a single cylinder four stroke, water cooled diesel engine operated on diesel fuel and Pongamia pinata methyl ester (PPME) with exhaust gas recirculation. The effect of EGR on the performance and exhaust emissions of the diesel engine were analyzed. The results of this study may be concluded as follows:

1. When the engine was operated with PPME, the brake thermal efficiency decreases due to the lower calorific value and high viscosity of PPME compared to net diesel fuel. The brake thermal efficiency increases at low EGR rates for both the fuels. However, increasing EGR flow rates to high levels resulted in decrease in brake thermal efficiency for both net diesel fuel and PPME.
2. It is observed from the figure that the PPME emits higher NOx than diesel fuel at all loading conditions. The NOx emissions were decreased with increase in EGR flow rate for both net diesel fuel and PPME.
3. The emissions of smoke and HC were found to be lower with PPME. However, with the increase of EGR flow rates resulted in considerable rise in smoke and HC emissions for both net diesel fuel and PPME.
4. The specific fuel consumption for PPME was slightly higher than diesel fuel at all loading conditions when operated with and without EGR.

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